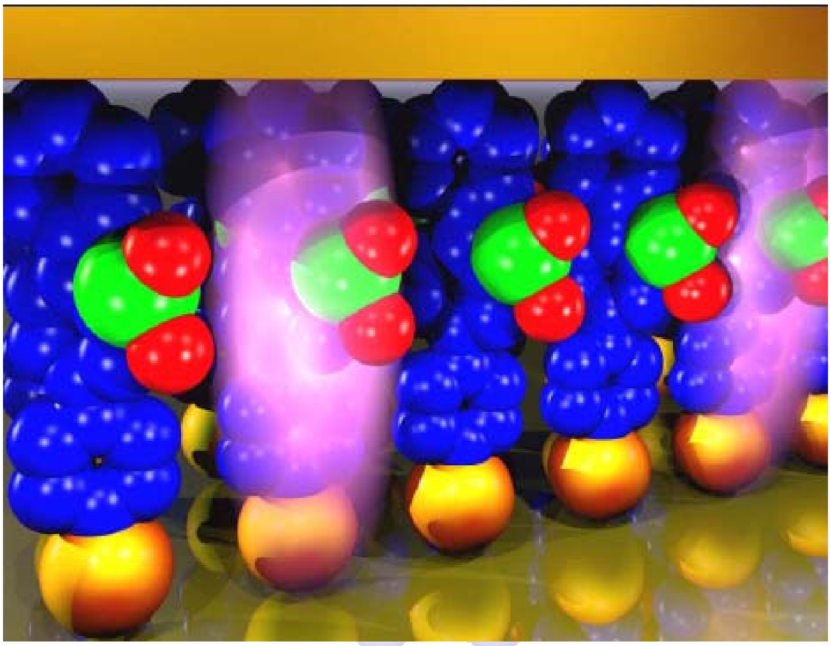
Moltronics-Future of microelectronics?



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Nano Materials Research Team

Outline

1. Organic semiconductors
   (1) Introduction-Definitions
   (2) Carriers of Charge and Energy
   (3) What happens in organic semiconductor?
   (4) How does conduction occur?

2. Organic semiconductor Devices
   (1) Measuring performance of organic devices
   (2) Structure and Process
   (3) Deposition and Morphology
   (4) Contacts
   (5) Patterning (all organic circuits)
   (6) Additional technology

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3. Electrical conduction in small molecules

(1) Cutting edge technologies

A. SPM
B. Transport

(2) Electrical conduction in small molecules

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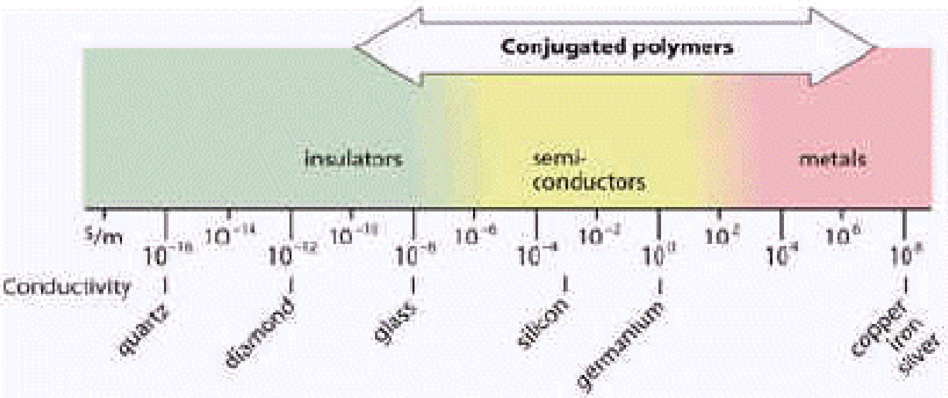
1. Organic semiconductors-- Definitions

Semiconductors

- Small but finite band gap
- Moderate number of carriers
- High carrier mobility

-Diamond
-Graphite
-SiO2
-PbSe
-Polycarbonate

-Silicon
-Germanium
-GaAs
-Polythiophene
-Pentacene



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1. Organic semiconductors-- Definitions

Organic Solid

- A material with carbon and hydrogen
- Typically characterized by spx hybridization
- Can be armorphous, crystalline or in between..

Polymers

Long, chain like molecules in which a basic unit is repeated a large, undetermined number of times

Olygomers

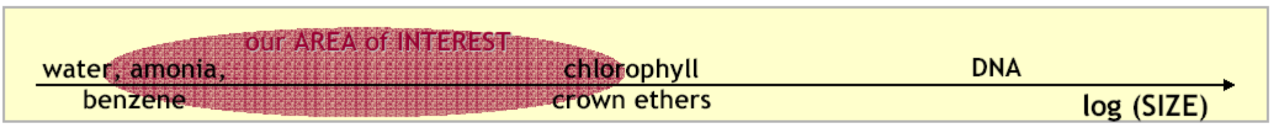
A low molecular weight polymer typically with two to five monomer units.

1. Organic semiconductors-- Definitions

Molecules

Derived from "molecula"-meaning small mass
(a smallest unit of chemical compound that still exhibits all its properties)

The size of the system



H. Haken and H. C. Wolf

Seeing the shape of molecules

TEM

What happens in organic semiconductors?

Traditional semiconductors

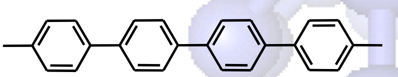
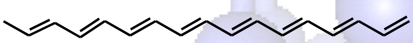
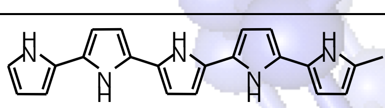
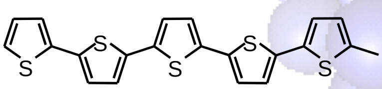
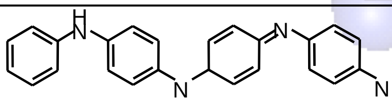
- Regulary spaced tightly bound lattice
(Bloch structure)
- Carriers are delocalized over a large area
- Both electrons and hole have good mobility
- Si, GaAs, Ge

Organic semiconductors

- Charges are able to hop from one chain to another and into/out of traps
- Carriers move through the solid in response to an applied e-field
(Field effect modulation of current and conductivity)
- Holes are generally more mobile than electrons(electron traps)

1. Organic semiconductors-- Definitions

Conducting Polymers

structures	polymer	doping	conductivity $(Scm)^{-1}$
	polyphenylene	Chemical (AsF_5, Li, K)	$500\text{-}1.5\times10^5$
	polyacetylene	Electrochemical, chemical	500
	polypyrrole	electrochemical	600
	polythiophene	electrochemical	100
	polyaniline	electrochemical	10

1. Organic semiconductors-- Definitions

Carbon is special I

- Carbon has several useful forms
- Carbon is not afraid to hybridize
- Carbon is a group 4 element
- Carbon's electronegativity is in the middle of the range-it prefers to share rather than steal or give up electrons
- Carbons bond readily with other carbons
- Carbon is small

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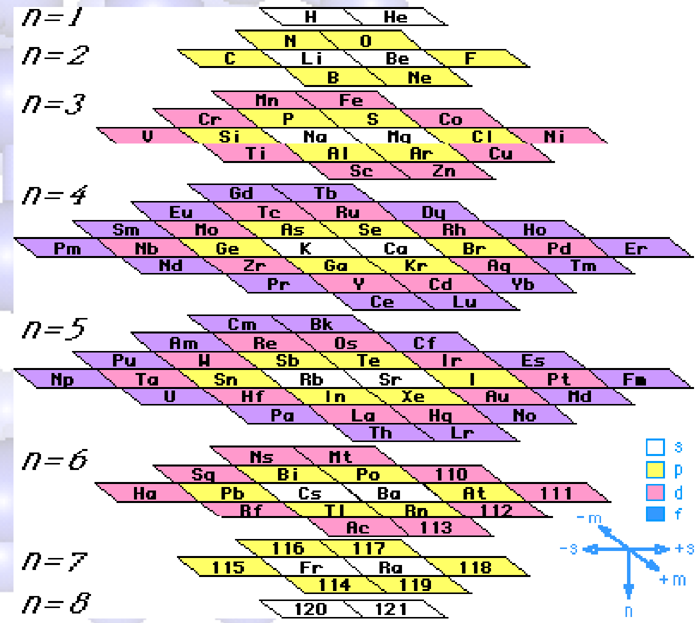
1. Organic semiconductors-- Definitions

Carbon is special I

Fluorine	4.2
Oxygen	3.6
Nitrogen	3.1
Chlorine	2.9
Bromine	2.7
Sulfur	2.6
Iodine	2.4
Carbon	2.5
Hydrogen	2.3
Phosphorus	2.3
Silicon	1.9
Iron	1.7
Sodium	0.9



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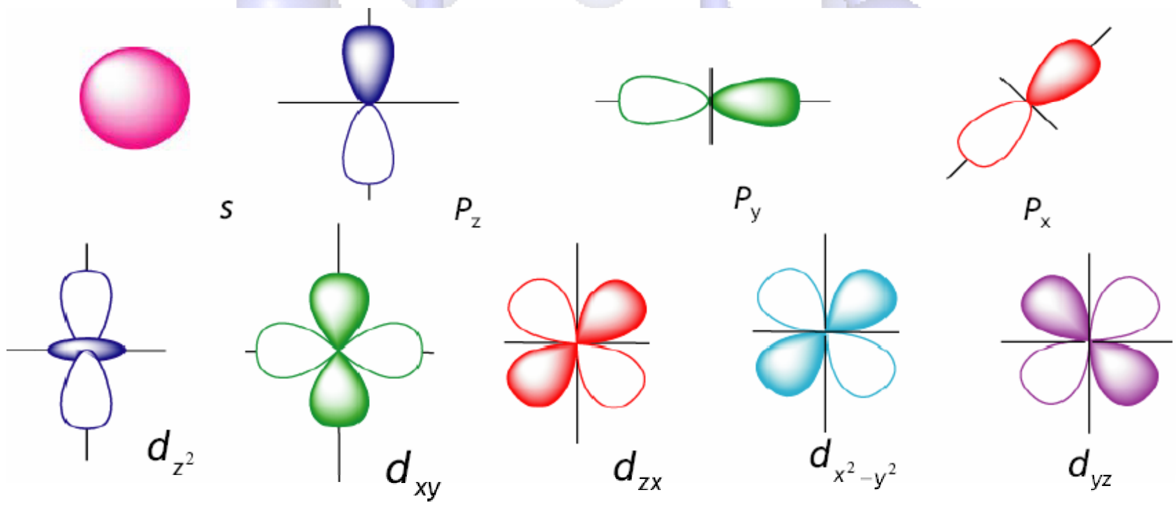
1. Organic semiconductors-- Definitions

Carbon is special II

Hybridized forms of carbon

Carbon has 6 electrons: $1S^2\ 2S^2 2P^2=[H]SP^3P^1_z$



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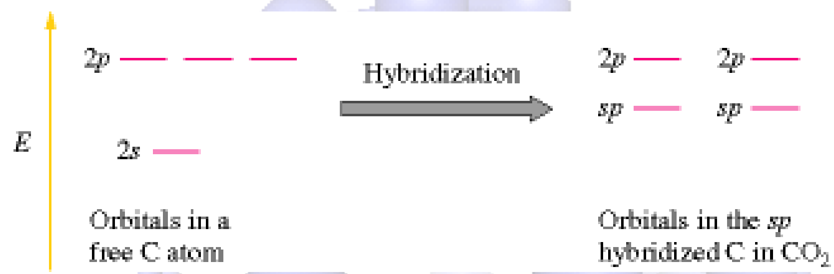
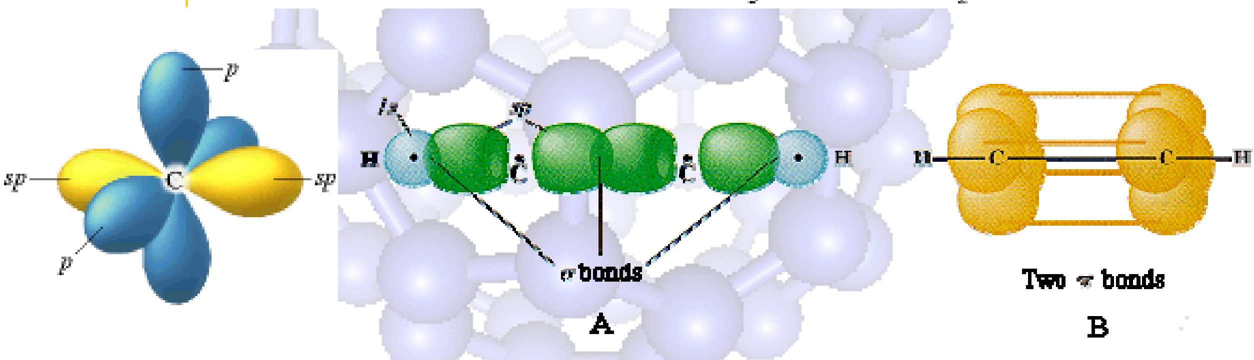
Sp hybridization





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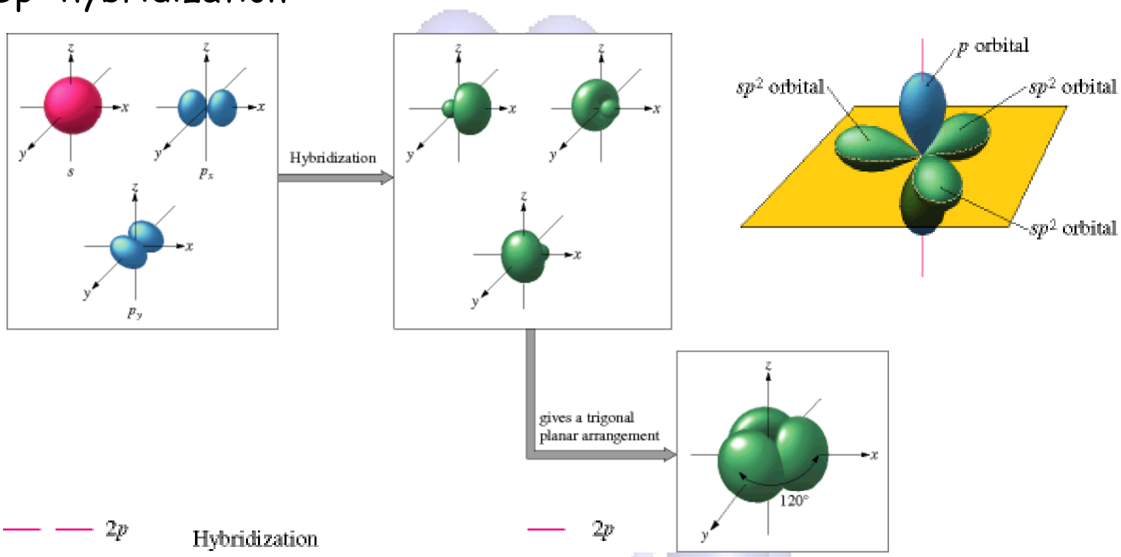
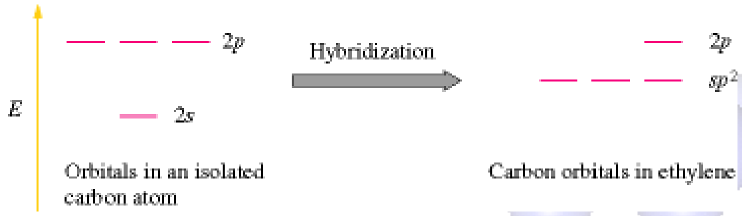
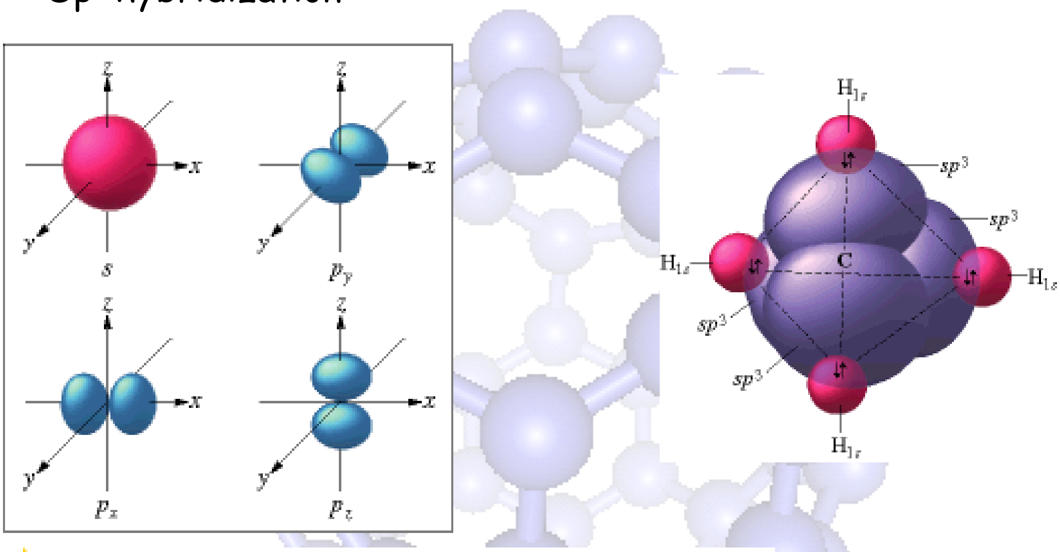
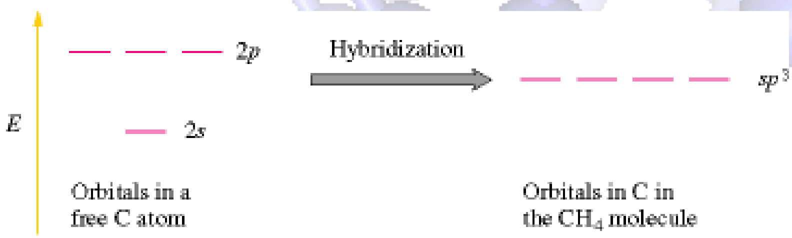
Sp² hybridization





Sp³ hybridization



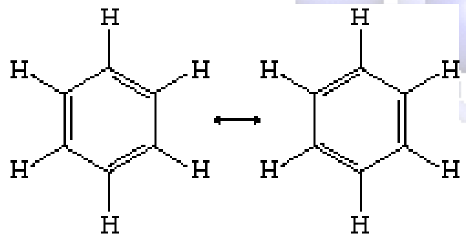


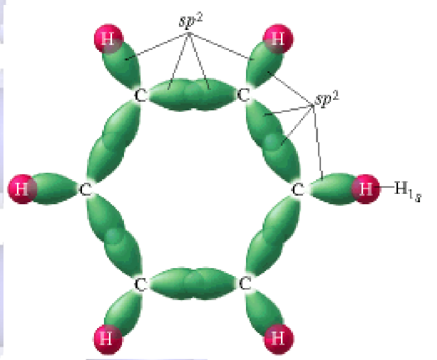
Hybridized forms of carbon

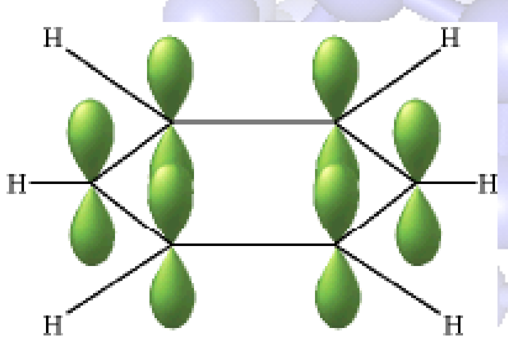
Carbon has 6 electrons: $1S^2\ 2S^2 2P^2 = [H]SP^3P^1_z$

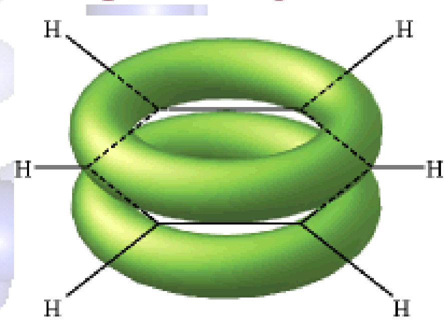
hybridization	# of hybrid	shape	Orbital interactions	bonding
sp3	4	tetrahedral	4 σ	4 single
sp2	3	Trigonal planar	3 σ 1 π	2 single 1 double
sp	2	linear	2σ 2π	1 single 1 triple or 2 double

Hybridization-delocalization-resonance









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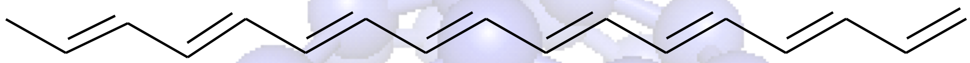
How does charge live on organic molecules?

- Polarons
- Bipolarons
- Exitons
- Solitions

Organic solids are covalent solids without electron overlap there are no significant hole and electron carriers in the traditional sense. Phonons appear to localize the charges.

Polyacetylene



Metallic plastic?
New material with the conductivity of a copper and the mechanical properties of plastic

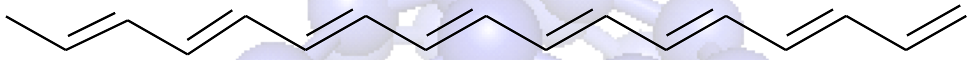
But nobody holds the C atoms fixed….

The position of C atoms is determined by the minimum energy of the system

$$E_{tot}=E_{electron}+E_{el-ion}+E_{ions}$$

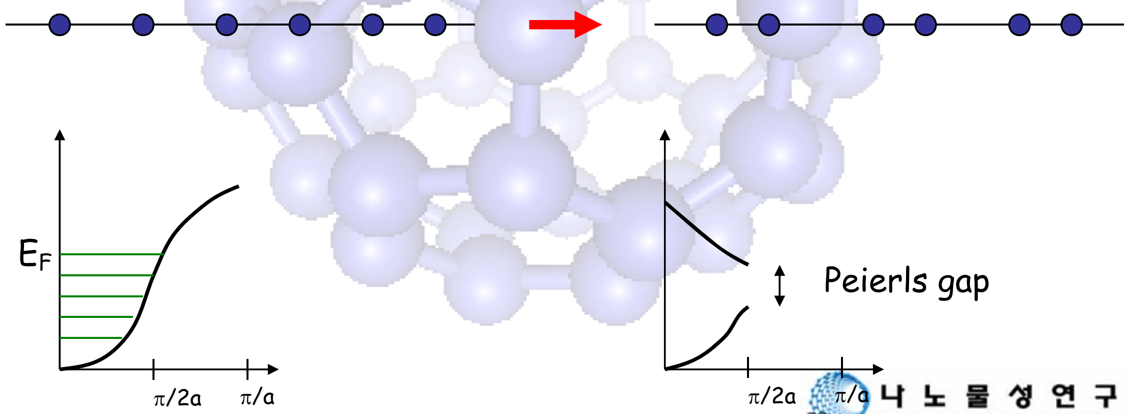
1 D metals are always unstable with respect to a lattice distortion of wavelength $2k_F$ Rudolf Pierls 1950's

Polyacetylene-electronic structure

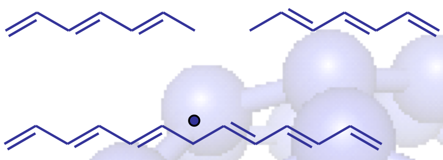


Sp2 hybridized carbon-1 π delocalized electron per C atom.

Suppose C atoms are disposed periodically,

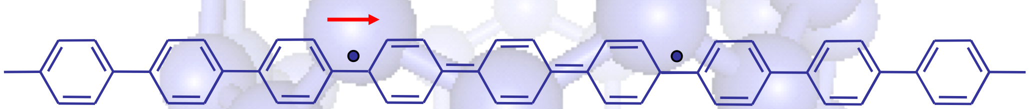


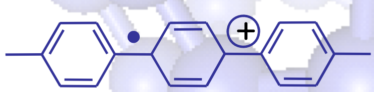
Conduction in organic semiconductors-Soliton



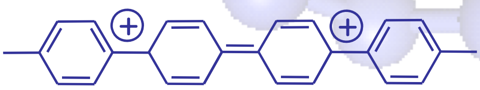
polyacetylene

polyphenylene





Polaron in polyphenylene



Bipolaron in polyphenylene

Zoo of solitons

Vacuum state

Neutral soliton

Positive soliton

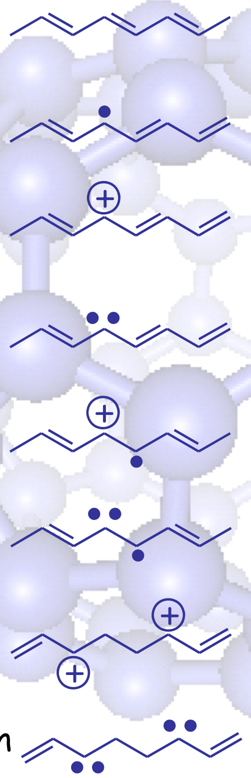
Negative soliton

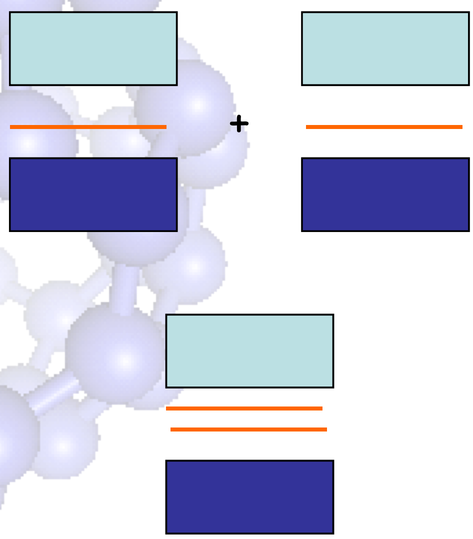
Positive polaron

Negative polaron

Positive bipolaron

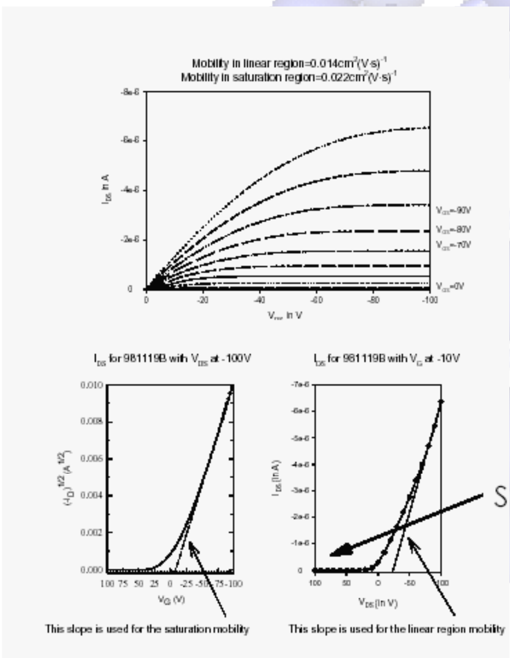
Negative bipolaron





Measuring performance of organic semiconductors

The most frequently cited values are mobility, on/off ratio, threshold voltage, and subthreshold slope



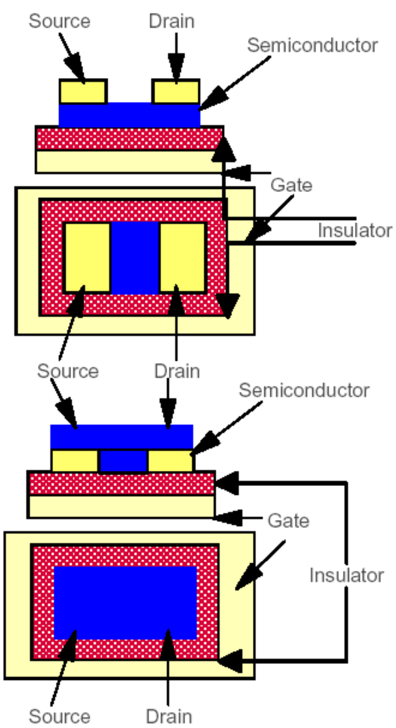
$$I_{D_{TRIODE}} = \frac{W}{L}\frac{\mu_{effective}C_O}{2}[2(V_G - V_T)V_D - V_D^2]$$

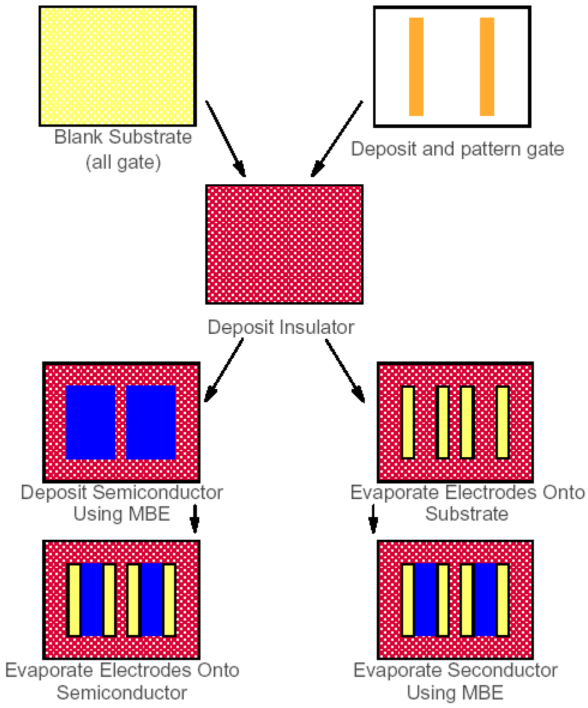
$$I_{D_{SATURATION}} = \frac{W}{L}\frac{\mu_{effective}C_O}{2}(V_G - V_T)^2$$

$$\mu_{effective} = \frac{L}{WC_O V_D}\frac{\partial I_{D_{TRIODE}}}{\partial V_G}$$

$$\mu_{effective} = \frac{2L}{WC_O}\left(\frac{\partial\sqrt{I_{D_{SATURATION}}}}{\partial V_G}\right)^2$$

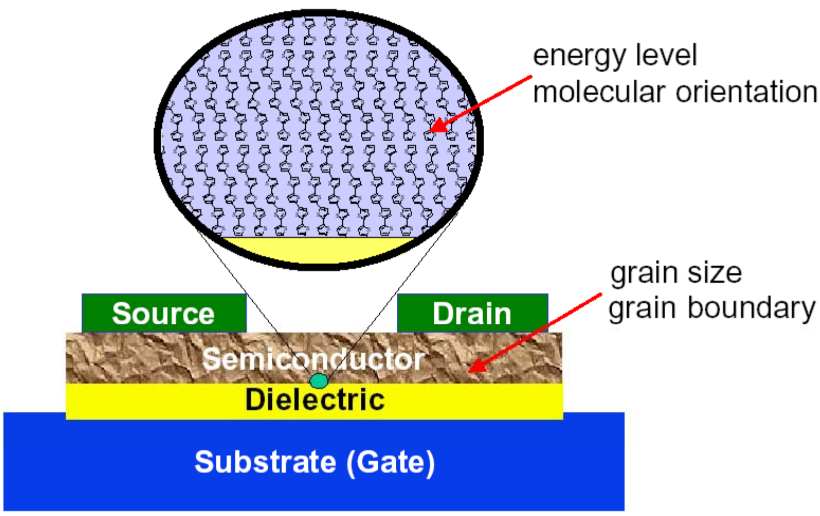
Structure and process



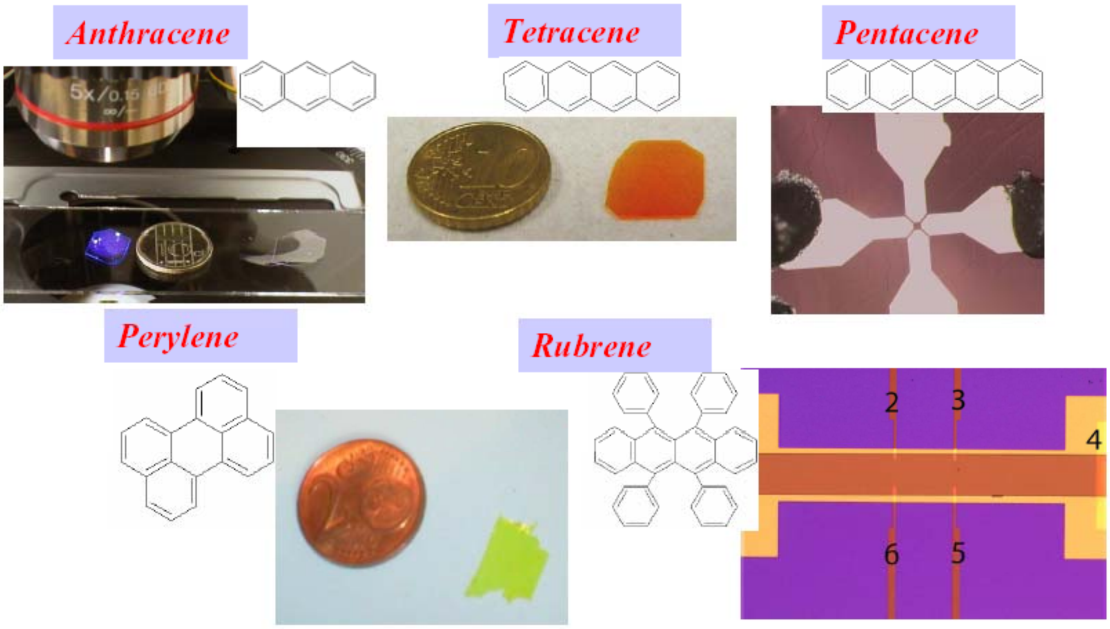


Deposition and morphology

Morphology and charge transfer relationship in organic semiconductors



Organic crystals



A. Morpurgo et al.

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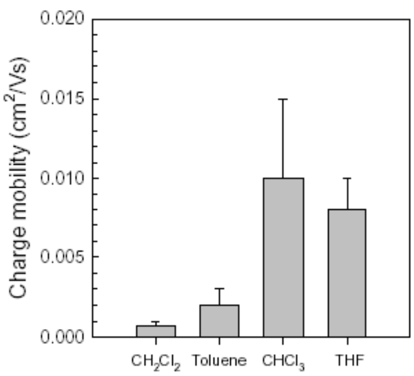
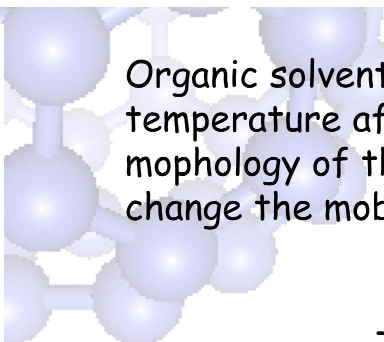
Organic thin films with different solvent

CH_2Cl_2 Toluene $CHCl_3$ THF





Organic solvent, substrate temperature affect the mophology of the film, thereby change the mobility

Z. Bao et al.

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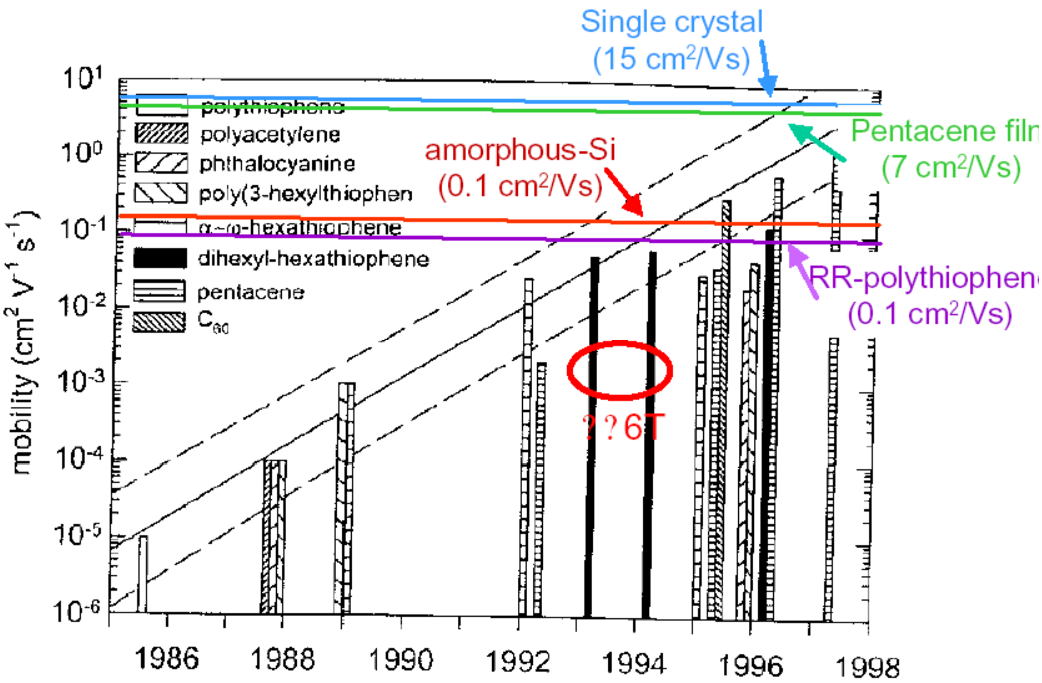
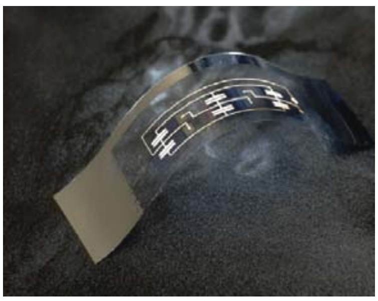


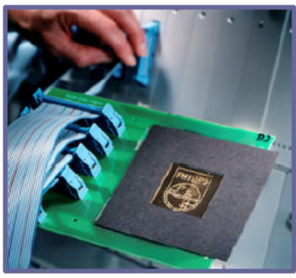
C.D. Dimitrakopoulos et al. Synthetic Metals 92 (1998) 47-52

Where do we use them?

Organic Electronic Devices: Displays, Memory Cards, Sensors

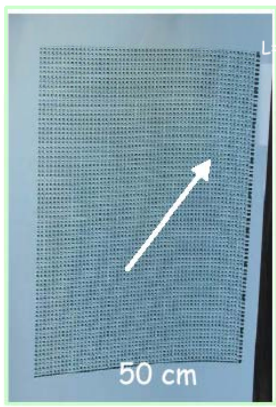
-------Electronics Everywhere

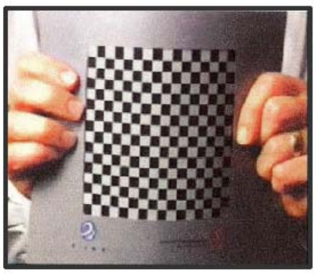




Philips

DuPont





Lucent/E-Ink

In the future?

Cutting Edge technologies in measuring small molecules

Can we achieve following criteria with Moletronics?

- Density
- Power dissipation
- Reliability
- Integration
- Speed
- cost